# Separation of MEG signals by independent component analysis

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## 1 Introduction

Independent component analysis (ICA) is a way to resolve signals into independent components based on the statistical characteristics of the signals. Magnetoencephalograms (MEGs) containing the brain signals as well as the noise from various sources such as the electrocardiograms (ECG), electromyograms, the earth magnetism and the device noises which are mutually independent may be as appropriate target for ICA. We applied ICA to the epileptic and the visual evoked fields (VEF) for separation of noise and signal components.

## 2 Methods

### 2.1 Algorithm of data processing

### 2.1.1 ICA

ICA was conducted in two steps. The first step was sphering to transform the data into an appropriate space and decrease the redundancy of the observed data. Sphering can be done by Principle Component Analysis (PCA) or Factor Analysis (FA). It has been shown that FA is more effective than PCA for noisy signals [1].

In FA the biomagnetic data **b** is modeled as,

$$\mathbf{b} = \mathbf{A}\mathbf{f} + \Sigma . \qquad (1)$$

Where $\mathbf{A}$ : factor loading matrix

$\mathbf{f}$ : factor of sources

$\mathbf{\Sigma}$ : normally distributed noise.

Here, **f** is the *m* dimensional vector.

In equation 1, **A** and **Σ** can be estimated by minimizing the likelihood function below,

$$\mathbf{L}(\mathbf{A},\Sigma) = -\frac{1}{2}\{tr(\mathbf{C}(\Sigma + \mathbf{A}\mathbf{A}^{\mathbf{T}})^{-1} + \log(\det(\Sigma + \mathbf{A}\mathbf{A}^{\mathbf{T}})) + n\log 2\pi\} . \qquad (2)$$

Where $\mathbf{C} = \sum \mathbf{b}_i \mathbf{b}_i^T / N$

$N$ : sampling number of observed data (data strength).

However, in equation 2, **A** and **Σ** cannot be uniquely determined, since *m* is unknown. Therefore, **A** and **Σ** are estimated for various *m*, and those minimizing the description length (MDL) shown below as the optimal one,

$$\mathrm{MDL} = -\mathbf{L}(\hat{\mathbf{A}},\hat{\Sigma}) + \frac{\log N}{N}\left(n(m+1) - \frac{m(m-1)}{2}\right) . \qquad (3)$$

The second step was rotation for better signal separation, which was conducted by Joint Approximate Diagonalisation of Eign-matrices (JADE) algorithm, which makes the kurtosis of the data independent by axis rotation of the FA space [1].

Altogether, ICA signals are given as

$$\mathbf{x}(t) = \mathbf{F}\mathbf{b}(t) . \qquad (4)$$

Where $\mathbf{F} = \mathbf{W}\hat{\mathbf{A}}^{-1}$

**W**: rotation matrix.

### 2.1.2 Reconstruction of MEG signals

After selection of ICA components representing brain signals, the MEGs were reconstructed by inverse-transforming those ICA components through the inverse of **F**. MEG signals generated by the *i*th ICA component are reconstructed as,

$$\hat{\mathbf{b}} = \mathbf{F}^{-1}\tilde{\mathbf{x}} . \qquad (5)$$

where $\tilde{\mathbf{x}} = [0 \;\; 0 \;\; ...... \;\; \mathbf{x_i} \;\; ...... \;\; 0]^T$ .

### 2.1.3 MEG signal analysis

The MEGs were analyzed by Equivalent Current Dipole (ECD) estimation, and Spatial Filter (SF) method [3].

### 2.2 MEG Recording

Informed consent was obtained from all subjects prior to the study. The epileptic MEGs and electroencephalogram (EEG) were simultaneously recorded from two patients.

The first patient (case 1) was a 50-years-old male suffering from simple partial seizures. Magnetic resonance imaging (MRI) showed a tumor in the medial area of left temporal lobe. MEGs and EEGs were recorded from the patient by a magnetometer (Shimadzu Biomagnetic Imaging System, SBI-100) constructed of 43 vector type gradiometers (band-pass filter, 5- 60 Hz).

The second patient was a 52-years-old female who had symptoms of complex partial seizures. MRI showed a lesion in the right hippocampus. MEGs and EEGs were recorded by a magnetometer (Shimadzu Whole-head Biomagnetic Imaging System) constructed of 201 radial type sensors (band-pass filter, 1-100 Hz).

Finally, VEFs evoked by two types of visual stimuli were recorded by SBI-100 from a healthy man (aged 22, right handed) using two visual stimuli (band-pass filter, 1-100 Hz) and averaged 50 stimulation trials. The first stimulus was the homogenous motion (HM) where random-dots moved in uniform directions and the second was the segmented motion (SM) where random-dots moved in the opposite directions between the neighboring segments.

## 3 Results

### 3.1 Isolation of the epileptic signals from normal brain signals

In case 1 of epileptic recording, MEG signals were separated into 27 components by ICA. Major ten ICA components having relatively large contribution (weights of the inverse-transform matrix from ICA to MEG) to MEGs and EEGs are shown in Figure 1. Only one ICA component (ICA component #6 in Figure 1) was synchronized to the epileptic spike in EEG (EEG-T3 on the dotted line). The results of SF analysis focused on the location of the dipole source determined by ECD (Figure 2) are shown in Figure 3b in comparison with those for MEGs before ICA in Figure 3a. There was significant improvement in signal to noise ratio S/N (about 5 times) as well as localization of the epileptic activities by ICA.

In case 2 of epileptic recording, 3 epileptic spikes were detected and 40 ICA components were determined. Major ten ICA components and EEGs are shown in Figure 4. As in case 1, only one component (ICA#10 in Figure 4) was synchronized to the epileptic spikes (EEG-T4). The source dipole estimated by ECD is shown in Figure 5b for the MEGs reconstructed from this ICA component, in comparison with those estimated by ECD for MEGs before ICA (Figure 5a). The source dipoles for MEG before ICA were clustered around the dipole for MEGs after ICA. The fact that only a single ICA component was identified for 3 MEG epileptic spikes indicates that all of them are generated from a single epileptic source, probably from that identified by ECD for MEGs after ICA. Scattered epileptic sources for MEGs before ICA may be attributed to estimate errors due to noise.

### 3.2 Signal noise separation of visual evoked MEGs

Twenty ICA components were determined for MEGs evoked by HM and SM stimuli. Eight of them asynchronized to the stimuli were rejected and MEGs were reconstructed from the 12 synchronize components. The original MEGs and the reconstructed MEGs are shown in Figure 7. There was significant improvement in S/N (about 2 times) after ICA. The analysis of the reconstructed MEGs by SF focused on V2/3 (focus point shown in Figure 6) was able to reveal V1 area with roughly equal responses to HM and SM, and V2/3 area with much stronger responses to SM than to HM, and V5 area with much stronger responses to HM than to SM (Figure 8).

## 4 Discussion

In epileptic case 1 MEG and EEG contained robust noise of ECGs. ICA was capable of separating this noise as periodic (roughly 1 Hz) ICA components #1 and #5. In epileptic case 2 ICA was capable of identifying all of 3 epileptic spikes as a single component (#10), indicating the epileptic activities arise from the same origin. Therefore the scatter in dipole estimates for the original MEGs may represent the estimate errors due to noise. In VEF experiments ICA was unable to isolate activities in individual visual cortical areas but assisted the identification by improving S/N. In conclusion, ICA is a powerful tool to isolate brain signals contained in MEGs and to improve S/N.

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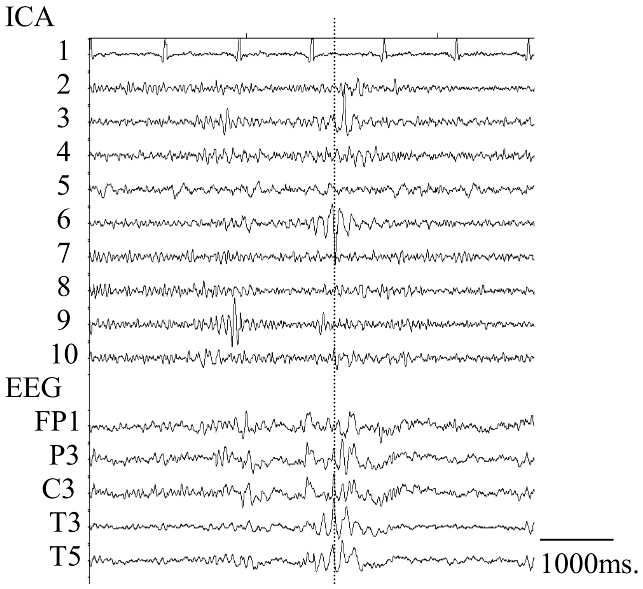

Figure 1: *ICA signals estimated from the epileptic MEG (case 1) and EEG signals.*

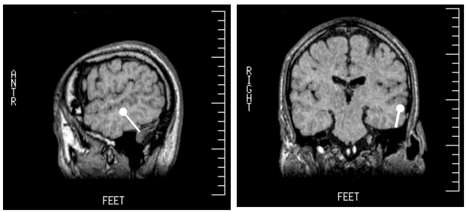

Figure 2: *ECD estimated from the epileptic MEG (case 1 ).*

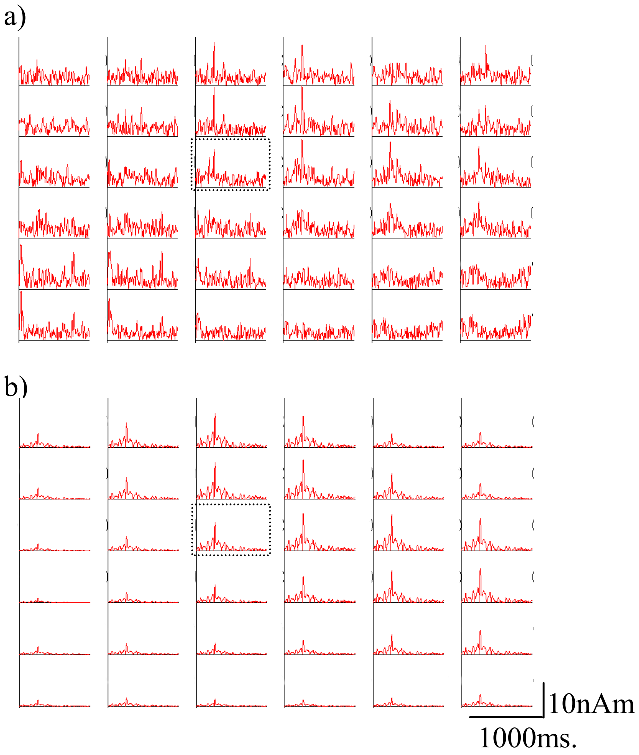

Figure 3: *SFs estimated from the epileptic MEG (case 1). The dotted box is the point corresponding to ECD shown in figure 2. a) SFs without ICA. b) SFs with ICA.*

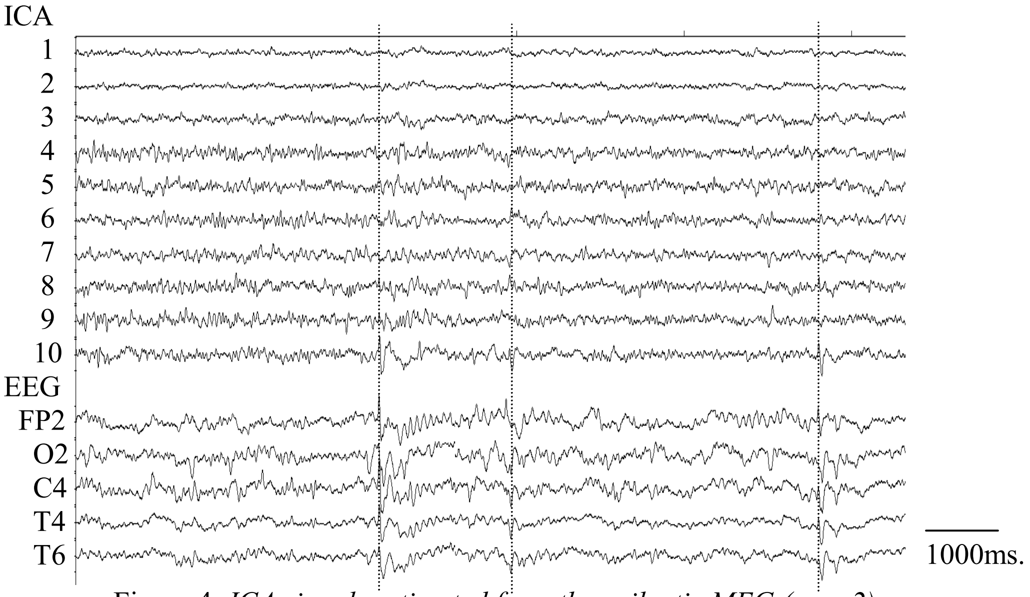

Figure 4: *ICA signals estimated from the epileptic MEG (case 2).*

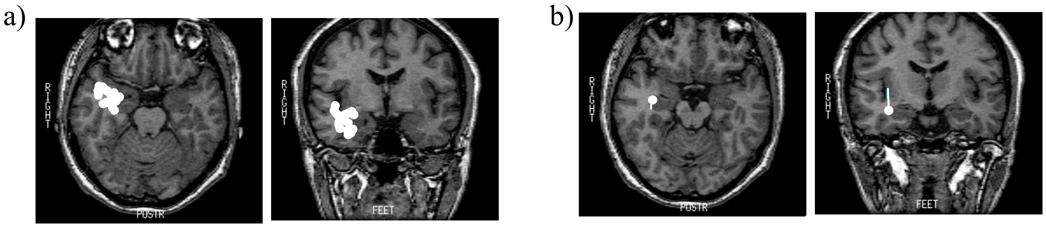

Figure 5: *ECDs estimated from the epileptic MEG (case 2), a)without ICA and b) with ICA.*

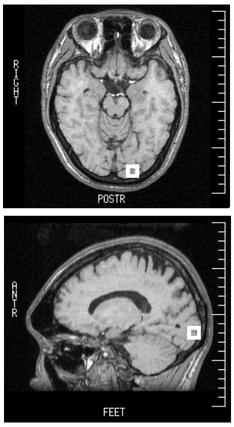

Figure 6: *SF focus for VEF analysis.*

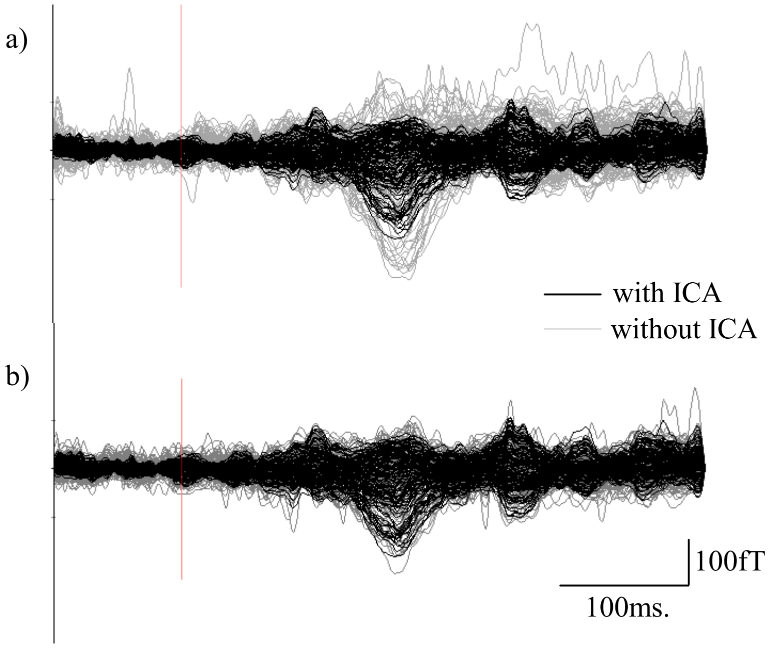

Figure 7: *The observed VEFs and the reconstructed one by selecting the brain ICA signals, a) SM and b) HM.*

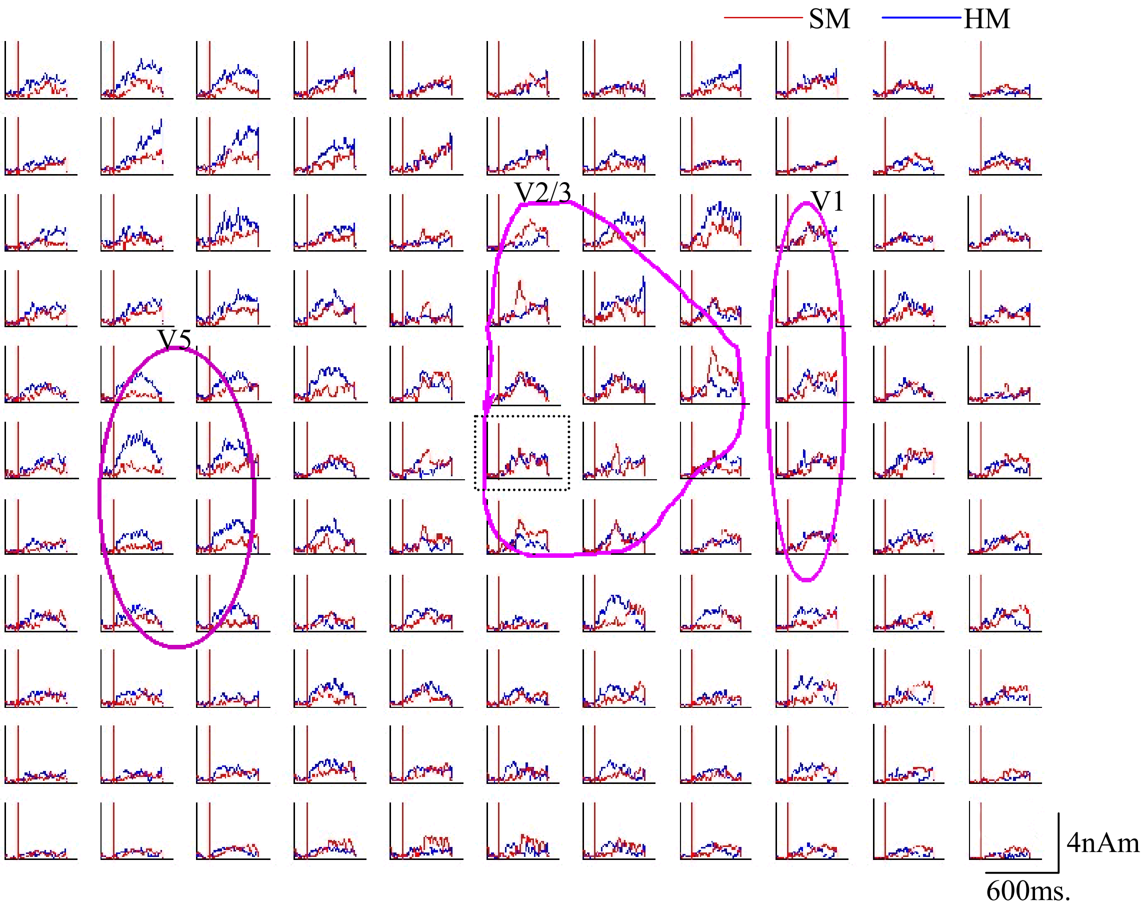

Figure 8: *SFs estimated from the reconstructed MEG in VEF. The dotted box is the focus shown in figure 6.*